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ABSTRACT

The diligent use of two-way voice links via satellites substantially improves the quality and the availability of health care and educational services in remote areas. This improvement was demonstrated in several experiments that were sponsored by the Department of Health, Education, and Welfare and the National Aeronautics and Space Administration. From 1972 to 1975, these experiments used the ATS-1, ATS-3, ATS-6 (Applications Technology Satellites) to examine the benefits of several different service-delivery configurations, in which one-way video, two-way audio/data, and two-way links to 23 states were involved. (Author/EMH)

SATELLITE TECHNOLOGY DEMONSTRATION

FEDERATION OF ROCKY MOUNTAIN STATES, INC.

technical report

TR0417

THE VOICE/DATA COMMUNICATIONS SYSTEM IN THE HEALTH, EDUCATION, TELECOMMUNICATIONS EXPERIMENTS

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ABSTRACT

The diligent use of two-way voice links via satellites substantially improves the quality and availability of health care and educational services in remote areas. This improvement was demonstrated in several experiments that were sponsored by the Department of Health, Education, and Welfare and the National Aeronautics and Space Administration (NASA). From 1972-1975, these experiments used the ATS-1, ATS-3, ATS-6 (Applications Technology Satellites) to examine the benefits of several different service-delivery configurations, in which one-way video, two-way audio/data, and two-way links to 23 states were involved.

INTRODUCTION

The Department of Health, Education, and Welfare, NASA, and the Corporation for Public Broadcasting sponsored a variety of health and educational experiments using color video, audio, and digital communications via satellites. The purpose of the Health, Education, Telecommunications (HET) experiment was to show how present satellite communications technology could be used to increase the quality and quantity of health and education opportunities in rural-isolated areas in the Rocky Mountain States, Appalachia, and Alaska and the Pacific Northwest. The Federation of Rocky Mountain States (FRMS) was the Ground Systems Manager for most of the technical operations in this experiment.

The video material was distributed via a NASA satellite spacecraft, the ATS-6, using two 1° spot beams. Two transmitters provided an effective isotropic radiated power of 52 dBW at 2569.2 and 2670 MHz. Thus, 113 relatively remote sites--equipped with small terminals--received programming directly from the point of origin. The terminals consisted of: a 10-foot diameter parabolic antenna; a microwave preamplifier; and an indoor demodulator. The output of the demodulation was a standard video baseband signal which drove a color television receiver.

In addition to receive-only video transmissions, two-way voice/data communications links were provided via other NASA satellites (the ATS-1 and ATS-3) at 24 sites in the Rockies,

six sites in Appalachia, and 16 sites in Alaska. This communications link employed the VHF transponders, as did the Alaskan Indian Health Service. As shown in Figure 1, the elements of the communication system included a two-way voice/data terminal designated an Intensive Terminal in the Rockies; a Network Coordination Center (NCC) located on the ground floor of the Federation's office building; and a master earth station located 12 miles southwest of Denver in Morrison, Colorado. All two-way voice/data traffic was routed from the earth station to the NCC via leased telephone lines.

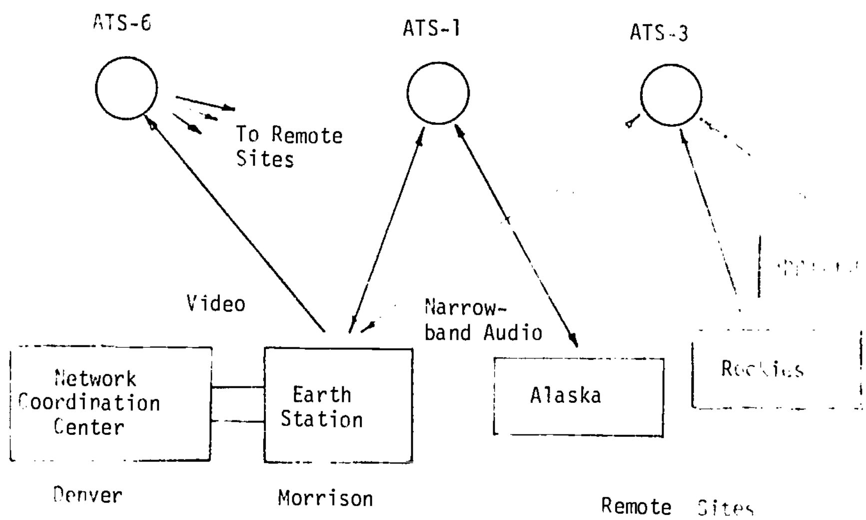

Figure 1. System Block Diagram of Voice/Data Communications Links

This paper describes: (1) the specially-designed, two-way voice/data equipment; (2) the operation of the voice/data network; (3) the limited digital student response keypads used to collect data; and (4) some results of the HET experiments. Emphasis is placed on the digital software and hardware, because these aspects represented the major innovation to network control and management. The utilization of hard-wired digital logic at the remote terminal provided maximum control flexibility for minimum cost.

EQUIPMENT

The Federation was responsible for the design, procurement, fabrication, integration, and installation of all the VHF equipment. As shown in Figure 2, the major elements of the VHF terminal included: a helical antenna that was used for simultaneous transmission and reception; a diplexer; a preamplifier; a transmitter/receiver, and a digital coordinator. The transmitter/receiver and digital coordinator were housed in a Budd cabinet that was rack mounted on casters with a desktop. The overall size was 51" high by 24" wide by 24" deep.

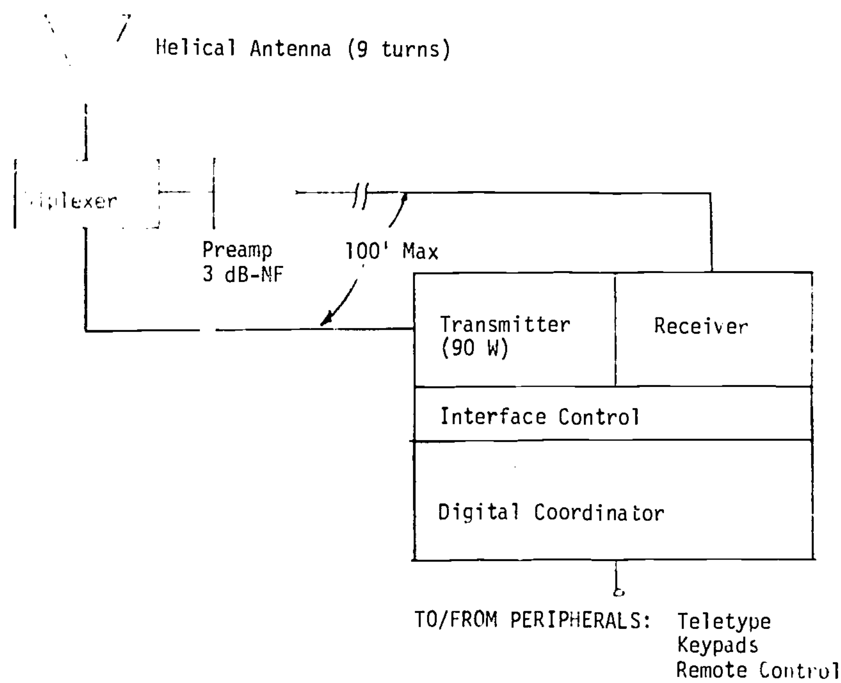

Figure 2. Block Diagram of VHF Terminal

The digital coordinator was the device which performed all control functions for the VHF equipment by sending and receiving digitally-coded commands to and from the sites to Denver. To simplify its use, the coordinator was designed to act as the complete control device for all the equipment, as well as to serve as the control panel for the VHF transmitter/receiver.

To conform with requirements placed on the HET experiments by the Interagency Radio Advisory Committee,there had to be an open receive channel at the remote site even during transmissions. Only in this manner was it possible to terminate transmissions from a remote site upon a command from NASA or the Network Coordination Center (NCC) during emergencies or unauthorized transmissions. Since this system operated in a half-duplex mode on each channel, the circuitry associated with the receive and transmit functions were independent. The block diagram in Figure 3 shows the functional circuits of the coordinator. The functions included the following:

Transmit Section	Transmit Automatic Data Generator Transmit Logic Control Unit (TLCU)
Receive Section	Receive Automatic Data Generator Byte Comparator Receive Logic Control Unit (RLCU) Byte 3 Decoder
Control Section	Control Logic Control Switches and Indicators

The coordinator achieved its major control function by sending and receiving a five-byte "preamble." Encoded in the preamble was a station code which allowed the remote site to monitor all calls made by the NCC to all stations in the network and to respond only to those calls made to a specific station. Digital data to and from peripherals attached to the coordinator was handled on a parallel seven-bit wide, bidirectional data bus. Use of the received data and source of transmitted data and source of transmitted data was defined by a seven-bit control byte sent as a part of the preamble. All transmissions by the NCC or remote sites were started by the transmission of a five-byte preamble. The preamble identified the remote sites and provided limited commands and remote control. The preamble was formatted as follows:

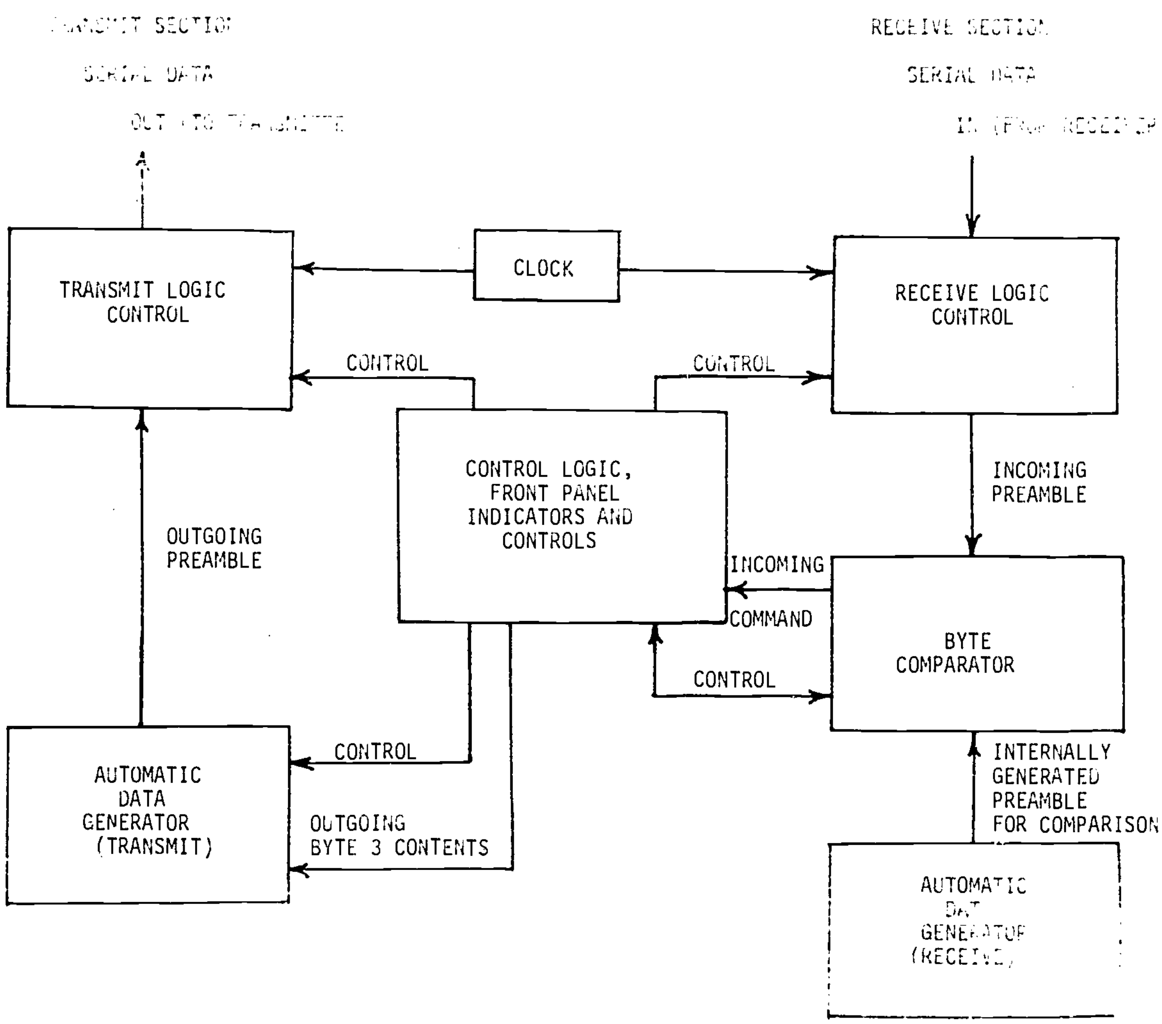

Figure 3. Block Diagram of Digital Coordinator

Byte 1 . . . . An ASCII character selected to signal the start of a preamble transmission

Byte 2 . . . . A seven-bit binary sequence--uniquely assigned to each remote site--which was used as the address or call number of a remote site

Byte 3 . . . . A seven-bit code byte--the key control factor in the system--which was programmed by the NCC and the remote sites to command remote sites to execute particular functions or to identify data being transmitted by the remote site

Byte 4 . . . . A repetition of Byte 3 to provide a redundant check

Byte 5 . . . . An ASCII character selected to designate the end of the preamble

Each time the call button was pressed, the activities in the coordinator were interrupted and the preamble was transmitted as a burst of five bytes. The preamble also was sent at the beginning of every transmission. The transmit section of the coordinator was composed of a transmit automatic data generator (TADG), a transmit logic control unit (TLCU), and associated control circuits. The terminal was configured to send three types of data: (1) preamble; (2) digital data from peripherals (parallel input); and (3) digital data from peripherals (serial data input). The first two types of data were sent through the TLCU where a start bit, two stop bits, and a parity bit were added to the seven-bit data byte. The resulting 11-bit byte was shifted out to the phase-shift keying circuits in the transmitter as a serial data stream. The third data type was sent directly to the FSK circuits as a serial data stream without processing.

The receive section was composed of the receive logic control unit (RLCU), the receive automatic data generator (RADG), the Byte 3 decoder, and the byte comparator. The terminal was capable of receiving three types of data: (1) preamble; (2) digital data to peripherals (serial data converted to parallel); and (3) digital data to peripherals (unprocessed serial data stream). Data of the first two types was a serial stream of 11-bit types containing one start, two stop, and a parity bit--the standard configuration for transmit functions. The RLCU removed the control bits and presented the seven-bit data byte in parallel on the data

bus, as well as in serial with a synchronizing clock. The third data type was available directly from the receive FSK output processing.

The byte comparator examined all data bytes received by the remote site; when a data block (preamble) containing the correct station address was received, it also responded to the command contained in Byte 3 of the preamble. Byte 3 was stored in a register to make it available for use in control circuits of the coordinator. The Byte 3 decoder was a collection of circuits which responded to unique Byte 3 codes. Examples of Byte 3 command functions were:

1. To configure a teletype to operate from the serial, unprocessed data stream.
2. To control the audio link to the NCC.
3. To start an interrogation cycle in a limited digital response system.
4. To serve as an alarm to each remote site.

The receive station was designed to examine each preamble so that no response was initiated in the coordinator until all five bytes were accurately decoded. If an error was encountered, then the byte comparator was reset to the beginning of the decode cycle. Failure to obtain a match in Byte 2 (station address) caused the comparator to return to scanning for a new Byte 1 start of preamble. Failures to obtain a match in Bytes 3, 4, or 5 initiated the transmission of a preamble to the NCC, with Byte 3 coded to indicate that the station call was recognized but that the message was not properly decoded and should be retransmitted.

Operator functions, such as control switches and status indicators, were contained in the control section along with the circuits required to properly time the turn-on of the transmitter with data and voice transmissions. The front panel switches allowed the operator to select between voice and data transmission modes. Indicator lamps were illuminated, according to modes selected by the NCC or peripherals. Additional circuits in the control section selected the Byte 3 code corresponding to the function being performed and inserted it into the transmitted preamble to inform the NCC of the service requested or used by the remote site.

Network Coordination Center Equipment

The major hardware components in the Network Coordination Center (NCC) were: a control; a display; and interface devices, most of which were custom designed for this application.

Control

The control function for the communications system was performed by two separate hardware items, each designed to act as the operating control device. The primary control device was the HP2100A computer; the secondary was the manual digital backup system. Since one was intended as a backup device, the system was functional with only one control device at a time. This control was selected by the NCC operator.

The HP2100A computer was designed for use in a real-time mode for network operations. There were three data flow and processing activities: (1) data was sent and received to/from the remote network sites; (2) data was sent to the earth station for control of the VHF equipment; and (3) data was sent to a visual display mapboard system in the NCC.

A CRT keyboard/display terminal was utilized in the NCC for network operator control of the computer. Each data input or output was processed through a separate I/O card in the computer to allow the proper priority interrupt to be assigned and to meet all software/system requirements.

Initial calls from remote sites on Channel 2, the coordination channel, were received on receiver number one at the earth station. Data preambles at the beginning of each transmission on Channel 4, the traffic channel, were received on receiver number two.

Because the outgoing signals to the remote sites were sent one at a time, only one I/O was used. The channel selected by the computer was appropriate to the data and remote site addressed. The controller at the earth station responded with its own unique address to the same formatted data preamble as did the remote site. The commands sent to the earth station controller were sent on the same data line as were the signals sent to the remote sites. Some of these signals were transmitted over the air, but the remote sites did not respond; similarly, the controller at the earth station did not respond to site commands.

The manual backup system was a hard-wired version of the computer with fewer functions. This system was interded for use when the computer was down or not "on line" for any reason. The manual system required more operator inputs and was limited in operational capabilities. The backup had only one data input and two data outputs. Channel 2 and Channel 4 data were combined in an OR gate for the input to the backup. This was done with the assumption that the probability of data preambles occurring at the same time on both channels is quite small. Data outputs were handled in the same manner as in the computer: One output was used for outgoing signals to the earth station controller or remote site; another, for signals to control the mapboard display system.

Display

Three display systems were used at the NCC: (1) the CRT terminal; (2) the manual backup system; and (3) the mapboard display.

The CRT terminal display was used when operating with the computer. Incoming calls were displayed on the CRT terminal to inform the Network Operator that a call had been received. Commands sent to the remote sites were displayed to maintain an active presentation of network status, and status of control functions at the earth station was retained to give the operator all information necessary to control the system.

The mapboard display system was used--both as an aid and as a general display--by all NCC operators. All remote sites were identified with lights. The sites with VHF capability were shown with a group of three lights: red, green, and amber. These lights corresponded to network activities as information was fed to the computer from the remote sites or the Network Operator. The system displayed real-time transmissions and gave the operator a quick overview of the entire network status.

The status display for the manual backup system was a set of digital numerical readout indicators. These indicators were arranged in a stack register to show the incoming signals according to station I.D. and the status of the site. Two numerical keyboards were provided for encoding station addresses and commands for outgoing signals.

Interface

Standard 1200 baud data modems were used for data traffic to/from the NCC and the Morrison earth station. In addition, tone encoder/decoders were used to send additional control signals along the same telephone lines used for data.

Figure 4 shows the interface device served several purposes. This device was used for conversion from Transistor Transistor Logic (TTL) to Electronics Industry Association (EIA) and EIA to TTL for interconnection of various devices. Routing of the signals (depending on control from the computer or the backup) was accomplished by electronic switching and signal conditioning in the interface device.

Morrison VHF Equipment

Figure 5 shows the block diagram for the VHF equipment located at the Morrison earth station. Note that the Morrison installation used equipment that also was used at the remote sites, including the helical antenna, the duplexer, the preamplifier, and the General Electric monitor receiver.

All receiving and transmitting equipment was for NCC traffic located at the earth station. As with the NCC's equipment, Morrison's equipment was categorized by function. Major functions at Morrison were transmitting, receiving, control, and interface.

A single, 300-watt, VHF-narrowband transmitter was used for all traffic outputs from the NCC. The transmitter was configured to transmit voice or data on any of three channels from any of several sources. Data modulation was FSK at ±4 KHz deviation.

All control functions for the transmitter were set up for remote operation from the NCC and usually were initiated by computer commands. Manual control by the earth station operator also was possible, as required by operational procedures.

Three receivers were used in the system in order to monitor the various incoming signals. Receivers number one and two received voice or data transmissions. These receivers were standard VHF monitors for demodulating the voice transmissions. A phase-locked demodulator was connected to the second limiter to demodulate the data transmissions. It was designed specifically to accept 70° -PSK data transmissions at a 1200 bits-per-second rate. Receiver number three was a standard monitor for voice only used for ATS-1 voice transmissions.

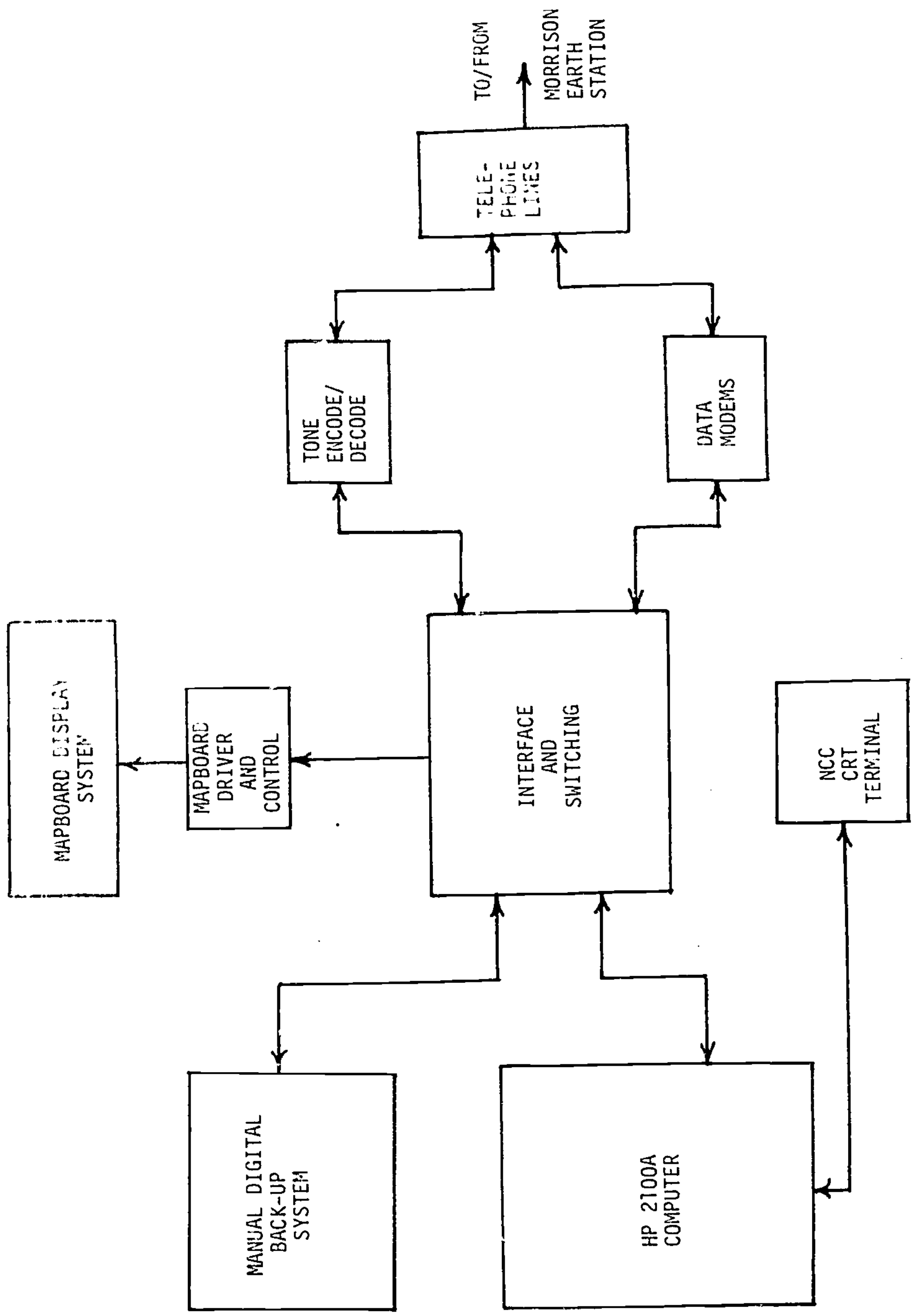

Figure 4. Block Diagram of Network Coordinator Center

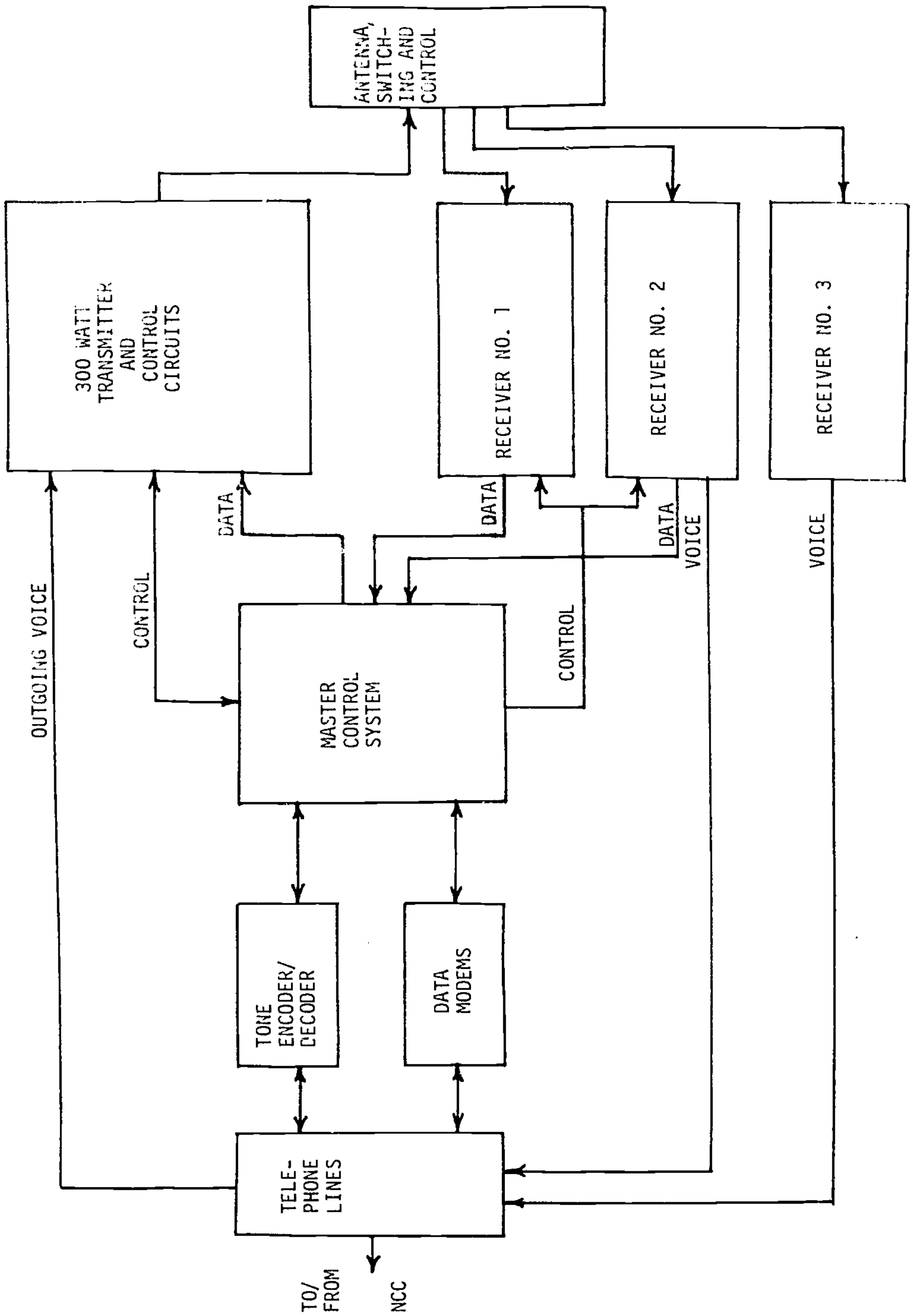

Figure 5. Block Diagram of Morrison Earth Station Equipment

The VHF master controller was a modified digital coordinator which accepted data preambles from the computer or backup in order to control the transmitter and receiver systems. Control items included: a transmitter key; a frequency selection; and an antenna system selection (ATS-1 or ATS-3). Standard modems and acoustic couplers were used to transmit the data via four phone lines to the NCC.

NETWORK OPERATIONS AND PROTOCOL

Network protocol was established to provide for smooth network operations. The basic functions were:

1. To establish a link between Denver and remote sites.
2. To arrange for links among remote sites for other HET network users.
3. To accept questions during the interactive mode of operation in the Rockies.
4. To monitor and record all transmissions.
5. To assist other HET network users with their programs and to help Network Operators to execute remote control functions.
6. To provide an automatic shutdown capability for the network in the event of an emergency or inappropriate use of the system.

Establishing Links

An appropriate place to describe protocol begins with the sequence by which a remote site established contact with Denver's NCC. Assuming that a suitable schedule was prearranged, the following events occurred:

1. A remote site-to-NCC link was established. To establish the link from a remote site, the remote operator pressed the "Call" button on his terminal, which initiated the transmission on Channel 2 of a preamble to the NCC encoded with the site address and the "Call" character. This was the only possible mode of operation available to the operator without control commands from the NCC. Upon detection and recognition at the NCC, the NCC operator could send either an "Acknowledge-Wait" signal or an

"Enable" command. The former indicated to the site operator that the "Call" was received at the NCC; due to network operation, however, transmission was not allowed. The latter indicated to the remote site operator that he could control voice or data transmission on Channel 4. Depending on the situation, the NCC could control individual sites or groups of sites; for example, if a group of stations was required to operate at the same time upon NCC-operator initiation, then the computer could send "Enable" commands to all these sites.

2. A remote site-to-remote site link was established. After establishing a link between the remote site and the NCC, any remote site could communicate with any other remote site on Channel 4. The only requirement was that both sites had to be enabled by the NCC, and that they had to follow HET network protocol. For Alaskan operations, the NCC could enable all sites automatically at the beginning of network operations.

3. Party-line operations were established. Any number of sites could be enabled. All that was required was for the NCC operator to transmit an "Enable" command. Thus, a party-line mode of operation was possible.

4. Interactive (voice) modes of operation were established. During some STD-allocated time on the ATS-6 spacecraft, the two-way voice/data system was used to facilitate voice interaction between remote site students and Denver instructor/moderators. After the initial checkout phase (15 minutes prior to the first hour of video transmission), most remote terminals were disabled. In order to initiate a conversation, the "Call" sequence would be repeated. This action did several things. First, by using a short digital burst to identify a calling station, the likelihood of a simultaneous seizure of the order wire was minimized. Second, with a CRT display of the incoming calls, the incoming calls were automatically queued and answered with an "Enable" signal or the "Acknowledge-Wait" signal. In this mode, all the active but disabled terminals still would have their speakers muted. All questions were patched into the associated audio channel of the video downlink so that all participants could hear the discussion.

5. Emergency procedures were established. As in any network, an operating protocol was established to deal with the following emergency situations: (1) national emergencies, such as natural disasters, civil defense alerts, and war; (2) spacecraft emergencies or failures; (3) NASA or FRMS facilities emergencies or failures; (4) remote site or regional center emergencies (Alaska, Rocky Mountains, Seattle-Omak, Appalachia); and (5) improper use of equipment at remote sites. In every case, the NCC Operator had the option to terminate any and all transmissions from remote sites (as long as the ATS-3 or ATS-1 were still operative) by a keystroke command to the remote digital coordinators. For the first three cases, the NCC Operator interrupted a transmission by either breaking in between transmissions or by disabling the enabled remote transmitters. The NCC Operator always explained the problem and gave instructions on how to proceed from that point. These instructions could range from a single "standby" to a complete station shutdown or evacuation. In the fourth case, the NCC Operator disabled all sites--except the site that was experiencing the emergency--in order to assist the disabled site in whatever way possible. In the event that the NCC Operator was aware of any improper activity at a remote site, he could at his discretion interrupt the site (the Denver earth station had a 300-watt transmitter and could therefore overpower most stations) and either deal verbally with the situation or, in an extreme case, disable the remote site and notify the proper authorities via phone.

SPECIAL FEATURES

The use of a digital coordinator permitted for a marginal cost increase, the introduction of three additional service-oriented features: remote control capabilities, teletype communications among sites; and real-time data collection from limited digital response keypad accessories.

Remote Control Capabilities

The digital coordinator could decode 20 separate commands. Eight of these were used for netwc'k operations. There were two pairs of commands available to turn on or off auxiliary

equipment. These remote control ports switched dry-contact pair relays with 110 VAC-15 ampere capacity. This feature could be used to turn on video tape recorders at the intensive sites to record supplementary films broadcast on the ATS-6 (at early-morning hours) for later use in the classroom.

Teletype Operations

The six sites in Appalachia used teletype to forward questions concerning the programming to the lecturers in Lexington. Questions were prepunched on a paper tape then transmitted upon voice agreement among operators. Frequency-shift keying--rather than phase-shift keying--was used to transmit the data permitting all stations to monitor teletype transmission and eliminating the need for phase-lock receivers at all sites. Interface signal conditioning was accomplished with basic integrated circuits. A null-zone detector was used to make the decision between a mark or a space. Using FSK in the full-power mode on the ATS-3, error rates better than 10^{-4} were observed. Commands were transmitted successfully with only 40 watts of transmitter power.

Real-Time Data Collection with Limited Digital Response Keypads

A data collection system was developed, which consisted of a 12-digit keypad with a single-digit display; ready, right, and wrong indicators; and a keypad poller with memory for interfacing to the coordinator. The keypad could be used in a variety of ways. At some sites, there was only one keypad; here, the terminal operator could enter protocol data or other types of desired research data as a string of up to 28 digits, each displayed as it was entered. To begin, the terminal had to receive a multi-digit mode command from the NCC. In this multiple-digit entry mode, the operator could correct any mistakes at the time of entry by depressing the "Period" button and reentering the digit. The string of digits was stored in a buffer; upon another command from the NCC, the data was transmitted using the PSK modulator.

Alternatively, the keypads may be looped together, since the system used a bus and since each keypad had a discreet address. Although this design allowed for only 28 keypads at a site, it easily could be expanded to provide more keypads. This permits real-time responses

from students to questions posed over the video link. For questions to which there were "right" or "wrong" answers, the proper digit for a "right" response was transmitted as part of the command which initiated the polling process. As each keypad was polled, its entry was compared to the "right" response and the "right" or "wrong" light that was illuminated on the keypad.

EARLY EVALUATION RESULTS

There were three major categories of evaluation: (1) technical performance; (2) operator utility; and (3) user utility.

Technical Performance

The primary areas of interest in technical performance included average signal-to-noise ratio, average intelligibility, failure rate of equipment, and meantime to repair actual failures or to diagnose other sources of downtime. The average test-tone, signal-to-noise ratio at the sites was on the order of 22 dB, based on the two-dimensional reporting system (signal strength and readability, range from 1 to 3). Although transmissions received at remote sites showed consistently usable quality, transmissions received at the NCC from remote sites were of marginal quality for a significant portion of the time the system was in use. The superior audio quality received at the sites is traced to the fact that the NCC voice uplink used a 300-watt transmitter which was more powerful than the 90-watt transmitters used at remote sites and thus was less subject to interference.

Poor intelligibility of the students' voices, as received in Denver, was attributed to: (1) imperfect filtering in the transmitters; (2) operation near threshold; (3) spin modulation on the ATS-3; (4) operation of the ATS-3 at half-power; and (5) radio frequency interference (RFI), which is more prevalent in the metropolitan area where the NCC was located. Further, since the incoming signals from the ATS-3 were rebroadcast on the video link of the ATS-6, the poor intelligibility degraded the utility to the viewers at the other remote sites. This problem was resolved by going to full power on the ATS-3 and by use of a high-gain, low-noise preamplifier, with a quad of helical antennas, at the Morrison uplink.

The failure rate was defined as the ratio of the number of program hours missed at all sites to the number of total program hours available. The failure rate for this new equipment was 1.9 percent. This measure ignores program time lost due to operator error which, during the startup phase, was the significant factor in overall downtime. As the meantime to repair the actual failures was usually one day, the actual downtime due to equipment failure was one program interval or less.

Operator Utility

Utility to the operators of this equipment was measured by: (1) the ease and speed with which they became proficient in operations, as shown by the number of operator errors; and (2) their own perceived view of the ease with which they became comfortable with their duties. Over 90 percent of the operator errors recorded in a four-month period occurred within the first month of operations. Subsequently, operator error was traced to site operator absence and operation of equipment by substitutes who had not been trained in equipment operation. It is interesting to note that in a midsemester questionnaire administered after eight weeks of operation, the operator's average opinion of the effectiveness of their training by the Denver staff was rated at 4.43 on a scale from one to five, in which four was "good" and five was "excellent." Although the equipment was somewhat complicated and there was a great deal of protocol to observe, nonprofessionals, given the proper training, did master the operation.

User Utility

In terms of utility to the user, an evaluation questionnaire administered to over 1,000 STD students revealed that after eight weeks, 80 percent enjoyed the interaction. The results of the teacher-training experiment in the Appalachian Educational Satellite Program indicated an overwhelming acceptance of, and appreciation for, the use of written feedback via the teletype network, on the part of both the lecturers in Lexington and the student teachers at the 15 sites. Similar results have been reported in the medical teaching programs conducted by the University of Washington and for the health services programs at Alaskan health sites administered by Indian Health Services.

SUMMARY

A description of the elements and the operation of a dedicated two-way voice/data satellite communications system has been presented in this report. The Health, Education, Telecommunications (HET) experiments generated considerable user interest in having audio or data interaction as an extra service in health and educational distribution systems using one-way video. This interest and acceptance should be considered by planners in future media distribution systems employing satellites, phones, and cable systems.

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